S282 Astronomy

Filaments and prominences

Study time: 45 minutes

Summary

In this activity you will be using images of the Sun that have been obtained from two major solar observatories in California and Austria to investigate the features of the Sun's chromosphere. This image-based activity uses the Hα image sequence set from 'The Sun' section of the Image Archive.

You will also need: a piece of thin string at least 30 cm long and a 30 cm ruler.

You should have read to the end of Section 1.3 of *An Introduction to the Sun and Stars* before starting this activity.

Learning outcomes

- Understand that prominences and filaments are features of the chromosphere.
- Understand that prominences and filaments are studied from images taken at the wavelength of certain spectral lines, and in particular, the Hα line.
- Appreciate the physical length scales associated with filaments.
- Appreciate the transient nature of filaments.

The activity

- Start the S282 Multimedia guide and open the folder called 'The Sun', then click on the icon for this activity ('Filaments and prominences').
- Press the Start button to launch the Image Archive at the required set of images.
- Alternatively, launch the Image Archive by clicking the Image Archive button in the Multimedia guide and then find the 'H-alpha images' sequence set which is located within 'The Sun' section of the archive.
- Place the cursor over one of the thumbnail images at the bottom of the screen – the date of the observation should appear.

A quick look at any of the images in the Hα image set will show you that this is not a familiar view of the Sun. Both observatories use digital cameras known as charge-coupled devices (CCDs) to obtain these images, so the only disadvantage in viewing them in the comfort of your own home rather than travelling to the observatory to view them there is that we have reduced them in size to make them more manageable (unless of course you wanted a trip to Austria or California!)

- ■ What is the range of dates that these observations cover (you will need to scroll through the thumbnails using the arrows below and/or to the side of them).
- ❑ The daily images range over the two-month period 1 April 2002 to 3 June 2002.
- ■ Why do you think there are no images between 9–21 April?
- ❑ The atmospheric conditions weren't good enough to produce sufficiently high quality images.

It may have been cloudy (a condition only too familiar to astronomers from damp temperate countries) or it may be that there was too much turbulence in the atmosphere to produce an image that doesn't appear to be smeared or out of focus. The observatory sites have been carefully chosen to minimize the number of days when images can't be taken.

The Big Bear Solar Observatory (BBSO) was built in 1969 in the middle of Big Bear Lake, California, at a height of 2000 m. This is at a higher altitude than most of Europe north of the Alps.

- ■ Why do you think the observatory is located at high altitude?
- ❑ Observatories tend to be sited high up because the atmosphere at such sites is clearer and thinner.

Compared to other astronomical observatories, solar observatories have an extra problem because they are in use during the day. You have probably seen heat haze rising off a hot road on a clear sunny day and the shimmering effect it produces as the air moves. This is exactly what we need to avoid if we are to obtain clear images of the Sun. At the BBSO the lake's water heats up much more slowly than the ground and so the images are less distorted by this effect. Turbulent motions in the air near the observatory are also reduced by the smooth flow of the wind across the lake instead of the turbulent flow that occurs over mountain peaks and forests.

The observatory has four telescopes which are specially designed for solar observations: a 65 cm reflector and three smaller refractors of 25, 20 and 15 cm. The whole Sun images you will be using are taken with the 20 cm telescope, which observes the Sun from sunrise to sunset each clear day, obtaining an image every 30 seconds.

The Kanzelhöhe Solar Observatory was founded during World War II by the German Luftwaffe near Villach in the Austrian Alps, to research the effects of the Sun on the part of the atmosphere known as the ionosphere. It is now part of the University of Graz. Like BBSO they have an array of small telescopes continuously monitoring the Sun, as well as a larger one doing more specialized work. The whole Sun Hα images are produced at one minute intervals during the hours of daylight.

(If you want to find out more about these two facilities, you can visit the websites of the BBSO (www.bbso.njit.edu) and the Kanzelhöhe Observatory (www.solobskh.ac.at/index_en.php). Note, however, that visits to these websites are not included in the study time for this activity.)

Question 1

What do we mean by an Hα image, and why do we use them to investigate the chromosphere?

- Scan along the thumbnail images until you reach the image for 20/05/02.
- Click on the thumbnail to open the image.
- First take a good look at the whole picture, but note that to investigate the details properly you should expand it to full-size by clicking on the button above it.

Question 2

Look carefully at this image, noting any important large-scale features. Bearing in mind what you read in Section 1.2 of *An Introduction to the Sun and Stars*, do you notice anything surprising?

Question 3

Make a rough sketch of the image, labelling those features you can identify. Describe in detail any features that you can't identify.

You estimated the size of a plage in Question 1.13 in *An Introduction to the Sun and Stars*. You are now going to estimate the typical length of filaments by measuring them on the image.

Prepare your scale by using your ruler to measure the radius of the Sun on your image.

- Use the full-size image as it will be easier to measure the filaments.
- A useful tip for making available as much screen space as possible for viewing the high resolution image is as follows. Right-click on the link that says 'Click here for full-size image'. In the menu that appears, there should be an option to 'Open in New Window'. Click on this, and you will see the large-scale image open in its own window – a window that can be as large as the available screen area.
- If you can measure the whole diameter directly from screen, so much the better. Remember to move your head so that your line of sight is at right angles to the screen at each end of the diameter. Divide the diameter by two to find the extent of the solar radius on your screen.
- If you can't get the whole width of the image of the Sun on the screen, you will have to estimate where the centre of the image is and measure from there to the edge. Don't forget to estimate the uncertainty in this measurement.

For example, on my screen I displayed the full-size image as described using the tip given above. My screen isn't large enough to see the entire solar disc, but it does show the whole width of the Sun. By scrolling the image down a little, I could easily see the widest part of the solar image. This distance, of course, corresponds to the solar diameter, which I measured on my screen to be (250 ± 4) mm. Thus the extent of the solar radius on my computer screen is (125 ± 2) mm.

- Now label the long filament across the left-hand side of the southern hemisphere on your sketch as filament ‘A’ (as in Figure 2). Then choose five other filaments and mark them B–F on your sketch. (These don’t have to be the same filaments as marked in Figure 2.) You will have to use your judgement to decide where one filament stops and another begins. Try not to choose the six longest (or shortest), but select some long and some short ones.
- Measure the lengths of these filaments using the string to trace out their extent on the screen (not your sketch) and then measuring the whole length of string against the ruler. Remember to estimate the uncertainty in your measurements.

Question 4

(a) Use the solar radius scale you measured earlier to calculate the lengths of the six filaments A–F *as they appear on the solar disc*. Tabulate your results. (Note that the solar radius is $R_{\odot} = 6.96 \times 10^5$ km.)

(b) How long are the shortest and longest measured filaments?

(c) There are two reasons why the lengths that you have measured may be *underestimates* of the true lengths of these features. What are these two reasons?

As highlighted in the answer to Question 4, you have not yet taken account of any foreshortening of features that occurs when a filament lies close to the solar limb – you have measured the lengths of filaments as they appear in projection. Near the centre of the solar disc, we see the filament from directly above and its apparent length will be a good estimate of its actual length. If we measure filaments away from the centre of the solar disc the apparent length will be substantially shorter than the true length. It is possible to make corrections for this projection effect, and convert any apparent lengths into actual lengths. It would be a lengthy diversion to do this fully, since the conversion factor depends not only on the location of the filament on the solar disc but also on its orientation. For our purposes we can use an approximate correction to the apparent length of features at different locations on the solar disc as shown in Figure 1: the actual length can be estimated by multiplying the apparent length by the factor that is appropriate for the zone that the filament lies in.

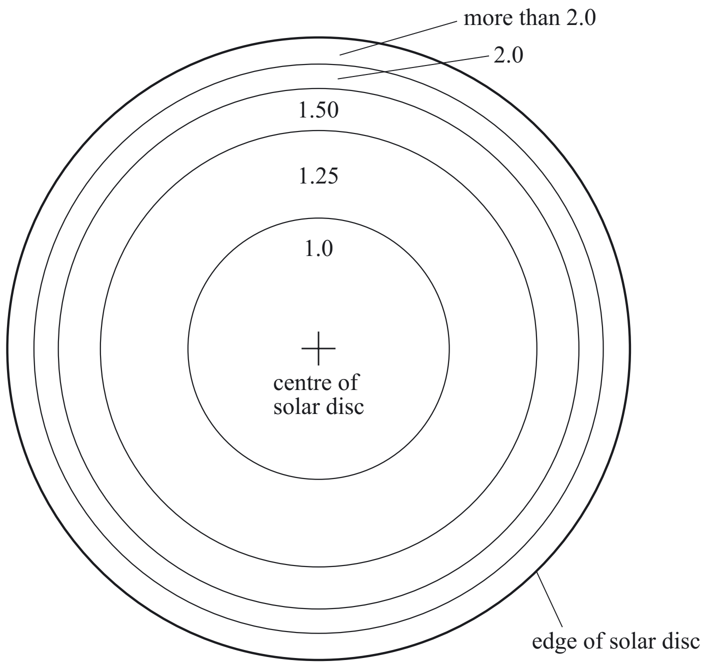

Figure 1 The factor by which the apparent length of any feature on the surface of the Sun should be multiplied to obtain its true length. This figure gives an estimate of this factor depending on where on the solar disc the feature is located. Note that this is only a very approximate correction factor – the true correction depends not only on the position of the filament on the solar disc but also on its orientation.

The major source of uncertainty in calculating the actual length of the filament is dominated by the uncertainty in the factor that is used to convert from apparent length to actual length. The uncertainty in an actual length that is calculated by multiplying the apparent length by the factor shown in Figure 1 is approximately as follows:

- Inner zone ‘1.0 zone’ – relative uncertainty of about 5%
- ‘1.25 zone’ – relative uncertainty of about 10%
- ‘1.50 zone’ – relative uncertainty of about 25%
- ‘2.00 zone’ – relative uncertainty of about 50%.

In the ‘more than 2.00’ zone, it is probably best not to use the factor as read from the diagram but to quote the apparent length as being a lower limit to the true length.

Question 5

(a) By reference to Figure 1, select the appropriate correction factor for each of your six chosen filaments.

(b) Complete your table of results for filaments A–F with their actual lengths and uncertainties.

We will now investigate the other reason why filament lengths might be underestimated –as you should have identified as an answer to Question 4. To find out whether filament A continues round the limb to the left we can note that the Sun rotates from left to right in these images. So you can look at the following day’s image – and see whether more of filament A has appeared.

- Try this now – view the Hα image from 21/05/02. (Note that if you opened the 20/05/02 image in a new window then the 'back' button on the web browser won't take you back to the Image Archive. You should close the new window, and use the original window that displays the image and the thumbnails. Provided that you didn't close the original window it should still be present on the taskbar.)

Question 6

Using the same techniques as before, measure the new length of filament A.

- Now have a look at the next few days' images, up to 25/05/02, and observe the way that the large-scale features change from day to day.
- A good way to do this is to open two or three images in separate windows and then flick between them. Again, you can maximize the amount of screen space by right clicking on the thumbnail and then selecting the option to 'Open in New Window'.

Question 7

What do you notice about how the images change from day-to-day?

If the features evolve in this way, how long do they last? To answer this question we need to look at the images over a longer timescale.

- If much of filament A lies at a latitude of about 30–40°, how long is its apparent period of rotation, i.e. how many days before 25/05/02 would we expect to see it in the same place, if it already existed then?
- ❑ From Figure 1.7 of *An Introduction to the Sun and Stars*, the intrinsic period of rotation at 35° is about 27 days. So the apparent period is about 29 days because the Earth has moved around the sun in its orbit during the 27 day period.

28 days before 25/05/02 is 27/04/02. Unfortunately there is no image for this date, but you can look at the image for the following day 28/04/02, 27 days before 25/05/02.

Question 8

Compare the image of 28/04/02 with that of 25/05/02. What do you notice?

Now go back another 27 days to the first available image – 01/04/02. Again, try opening the three images in three separate windows, so that you can flick between them.

Question 9

Compare the image of 01/04/02 with that of 25/05/02. What do you see now?

So from the limited data you have available you can't give a definitive answer to the question of how long the features last. But you have seen that although they

clearly evolve over a timescale of days and some filaments, for example, appear to last no more than a couple of weeks, some of the main features such as plages and major filaments have lifetimes that can be measured in months.

Having got this far, you may like to spend some more time tracking filament A as it evolves!

Answers to questions

Question 1

An Hα image is one where all the wavelengths of light (colours) have been filtered out except for a narrow band of red light around 656.3 nm, corresponding to the Hα line of the hydrogen spectrum. When we observe the Sun in ordinary white light – i.e. a mixture of all the visible wavelengths – the brilliant photosphere far outshines the far dimmer chromosphere overlying it. However the hydrogen atoms in the chromosphere are very efficient at emitting and absorbing photons from the transition between energy levels E_2 and E_3, which correspond to light of wavelength 656.3 nm. (See *An Introduction to the Sun and Stars*, Box 1.2). So hydrogen atoms in the chromosphere absorb most of the light that comes from the photosphere at this wavelength, and emit light of their own in at this wavelength. You can see an example of the reddish chromosphere emission in *An Introduction to the Sun and Stars*, Figure 1.17. Hence the detail we can see in an Hα image comes from the chromosphere rather than the bright photosphere.

Question 2

The image is the same brightness right across the disc; it doesn't show any limb darkening (Section 1.2.2, Figure 1.3). This is not an effect of the type of image – most of the light that is seen in an Hα image originates from the photosphere (remember that such light is absorbed by gas in the chromosphere) and hence such images should show limb darkening. However, the images have had their contrast enhanced, effectively taking out the limb darkening effect so it is easier to see the small-scale details.

Question 3

Four types of feature are clearly visible on the Hα image as shown in the sketch in Figure 2. These are filaments, prominences, plages and sunspots.

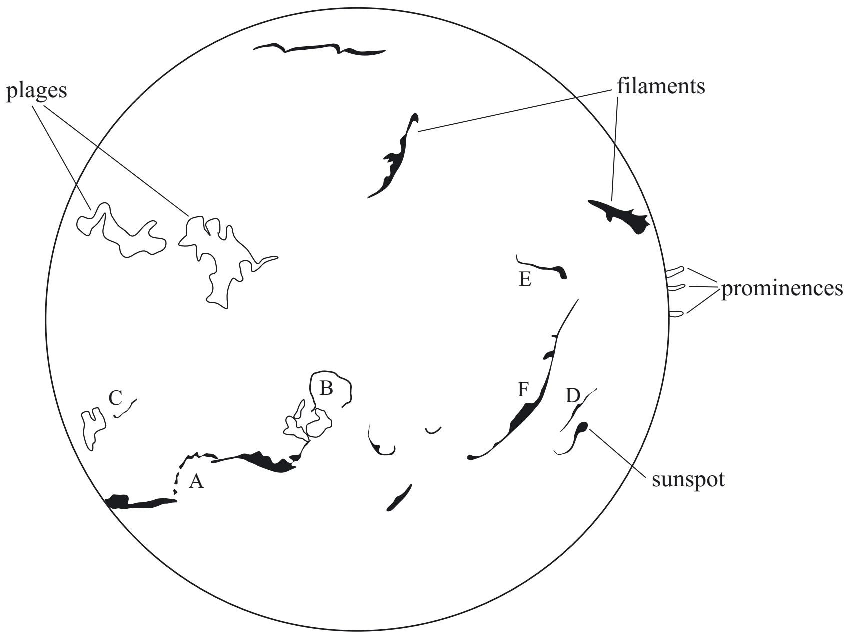

Figure 2 An example of a sketch of the features visible in the Hα image taken on 20/05/02. Note that the labels A–F denote individual filaments that are discussed in Question 4.

Notice the way that the long winding dark filament (call it filament A) across the left-hand half of the southern hemisphere turns into a prominence as you trace it leftwards towards the limb – towards the centre of the image you are looking straight down on it, but near the limb it becomes increasingly obvious that it has the form of clouds suspended over the photosphere.

You may have noticed that the small-scale features have changed subtly from the roughly circular convective granulations of the photosphere (Figures 1.11 and 1.12 of *An Introduction to the Sun and Stars*) to more elongated structures which show some sort of local alignment, in particular radiating out from sunspots. These features are governed by the local magnetic field, and are reminiscent of the sort of patterns iron filings make when dropped on to a sheet of paper with magnets underneath. The difference is because the density of the photosphere is high enough that mechanical energy determines its structure, whereas in the chromosphere the density drops off sharply (Figure 1.35) and the magnetic field dominates.

Question 4

(a) I have chosen the six filaments A–F shown in the sketch in Figure 2. You will probably have chosen some of the same – it doesn't matter if they are not identical.

The solar radius = $R_\odot = 6.96 \times 10^5$ km

So the length of filament A is given by

$(105 \text{ mm} \times 6.96 \times 10^5 \text{ km})/125 \text{ mm} = 5.85 \times 10^5$ km

The apparent lengths of all the filaments A–F are given in Table 1.

Table 1 Measured and calculated lengths of filaments for the 20/05/02 image.

Filament	Measured length on image/mm	Apparent length/km
A	105 ± 5	$(5.8 \pm 0.3) \times 10^5$
B	45 ± 5	$(2.5 \pm 0.3) \times 10^5$
C	15 ± 3	$(0.84 \pm 0.17) \times 10^5$
D	25 ± 3	$(1.4 \pm 0.2) \times 10^5$
E	40 ± 3	$(2.2 \pm 0.2) \times 10^5$
F	82 ± 5	$(4.6 \pm 0.3) \times 10^5$

(b) My shortest measured filament was C at 0.84×10^5 km, and the longest, A, was about 7 times longer at 5.85×10^5 km. I would be fairly confident that A is the longest filament on this image of the solar disc, but I think there could also be some shorter ones.

(c) There are two reasons why the actual lengths of filaments will be greater than the apparent lengths calculated here. The first is an effect that you met in Questions 1.2 and 1.10 of *An Introduction to the Sun and Stars* – that of foreshortening of features near the solar limb. The second reason applies only to filaments that extend to the limb – such as filament A here – we don't know from the image whether they continue round beyond the limb.

Question 5

(a) In most cases, the filament lies wholly or nearly wholly in a single zone on Figure 1. The corresponding correction factors are tabulated in Table 2. The most difficult case is filament A: this extends over several zones, and seems to disappear over the limb of the Sun. In this case, it is best not to try to adopt a correction factor, but to say that the apparent length is a *lower limit* to the actual length.

(b) The values of actual lengths are shown in Table 2. The uncertainties are derived from the dominant uncertainty – this is the uncertainty in the correction factor that is described in the text.

Table 2 The actual lengths of filaments A–F.

Filament	Correction factor	Relative uncertainty	Apparent length/km	Actual length/km
A	(see note)	–	5.8×10^5	$> 6 \times 10^5$
B	1.00	5%	$(2.5 \pm 0.3) \times 10^5$	$(2.5 \pm 0.3) \times 10^5$
C	1.50	25%	$(0.84 \pm 0.17) \times 10^5$	$(1.3 \pm 0.3) \times 10^5$
D	1.50	25%	$(1.4 \pm 0.2) \times 10^5$	$(2.1 \pm 0.5) \times 10^5$
E	1.25	10%	$(2.2 \pm 0.2) \times 10^5$	$(2.8 \pm 0.3) \times 10^5$
F	1.25	10%	$(4.6 \pm 0.3) \times 10^5$	$(5.8 \pm 0.6) \times 10^5$

Note: it is not possible to determine a correction factor for filament A, hence only a lower limit to the actual length is given.

Question 6

At first glance it certainly looks as if more of filament A has appeared. I get the same value for the diameter of the image – 125 mm – so the image is at the same scale, but now I measure the length of A as 120 mm. Hence my new estimate of the minimum length is $(120 \text{ mm} \times 6.96 \times 10^5 \text{ km})/125 \text{ mm} = 6.68 \times 10^5$ km, some 17 000 km longer than the previous day and now a length equivalent to nearly the solar radius. So our conclusion is that filaments range in length from a few thousand km to around half the solar diameter, or possibly even more. Remember that we have only studied one image in detail here.

Question 7

You can clearly see the large-scale features, i.e. the filaments/prominences, plages and major sunspots, moving to the right as the Sun rotates. As they move the shapes change subtly as parts of the filaments grow or shrink and the line of the filament moves about due to the shifting magnetic fields. This is partly due to the different angles of view as they move towards or away from the limb, and partly due to the actual evolution of the features.

Filament A seems to change between the 22 and 23 of May in that it is originally a continuous filament, but on 23 May it appears separated into two parts. On subsequent days the right hand part of the filament fades dramatically.

Question 8

The pattern of the main plages is very similar. As they are nearer to the solar equator than filament A, you would expect the period of rotation to be a little shorter, corresponding to using an image 27 rather than 28 days earlier. The pattern of the many of the smaller filaments is quite different, for example there are a pair of nearly vertical filaments just above and to the left of the most southerly of the main plage regions in the 28/04/02 image which seem to have completely disappeared by 25/05/02. However there was already a long filament in the region of filament A which, although it has changed shape, could be reasonably supposed to be the same structure. If you look closely you can see traces of this filament winding over towards the right-hand limb.

Question 9

Again, although the details change, some of the main features present on 28/04/02 clearly had their origins at least four weeks earlier. In particular, there was already a large filament in the southern hemisphere in just the position where we later find filament A.

Resources

The Big Bear Solar Observatory www.bbso.njit.edu

The Kanzelhöhe Observatory www.solobskh.ac.at/index_en.php